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Original scientific article

THE IMPACT OF AGROECOLOGICAL FACTORS ON MORPHOLOGICAL TRAITS OF MAIZE

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Climate changes are one of the crucial issues of modern agriculture. These changes imply the increase in average temperatures and the frequent occurrence of temperature extremes. Such conditions are stressful to maize concerning the expression of its traits. This paper presents the analysis of the maize yield concerning the yield components, morphological and chemical traits under various agroecological conditions. The objective of the study was to evaluate variability of grain yield (GY) and yield components (ear length, EL and number of kernel rows, NKR), morphological traits (plant height,PH and ear height, EH), as well as chemical traits (the whole plant dry matter, PDM and the ear dry matter, EDM), and the effect of the environment on the intensity of expression of these traits. Fifteen genotypes developed by crossing of six inbred lines were used as a material in the study carried out during the two-year period in one location. Obtained results indicate that traits were more pronounced in maize hybrids than in the parental components including the lower variability of the traits expression. NKR did not affect the yield unlike the EL, whose coefficient of determination was $R^2 = 0.600$ in both production years. The environmental effect was high for all traits except NKR. PDM and EDM were closely related to PH and EH, but they also depended on the EL and the NKR.

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Variations in meteorological conditions have a significant impact on the final goal of the production, the yield. Prevailing agro-ecological conditions should be a major guideline in planning the crop production and selecting the genetic material.

Key words: yield, yield components, variability, environment

INTRODUCTION

Today, more than ever, attention is paid to agro-ecological conditions and issues of climate changes. Global warming has a great impact on changes of the environment, that leads to the modification of the duration of the growing period, genetic and physiological processes and limiting effects on yield components (SADRAS and SLAFER, 2012), and yield improvement (SLAFER *et al*., 2014). At the same time, agricultural production is greatly influenced by weather extremes and climate variability (CANTELAUBE and TERRES, 2005), variations beyond synoptic weather frames of intermediate states and other properties of the climate system (CUBASCH *et al*., 2013). Within the seasonal meteorological variability, weather conditions can affect crop production during all stages of the crop development: directly through the effects of temperature, water availability, radiation interception and carbon fixation and indirectly through modulating nutrient availability and the onset of disease and pests (OLESEN *et al.*, 2000).

PARENT and TARDIEU (2012) have described the maize developmental stages in relation to the temperature. The normal proceeding and the development of all phenophases occur up to the temperature of 30ºC, after which they abruptly slow down. Several studies have pointed out to the impact of high temperatures on crop densities, the development of biomass as a consequence of the cycle shortening caused by high temperatures (RATTALINO-EDREIRA and OTEGUI, 2012). The appearance of silk and stamens also depends on temperature conditions (CICCHINO *et al*., 2010; ORDÓÑEZ *et al*., 2015), which is further related to some traits of yield components (EL, NKR, seed weight).

The relationship among yield components is important in plant breeding for the development of genotypes of high yielding potential and for the crop management optimisation (GOLBA *et al*., 2018). Furthermore, the relationship between yield and yield components depends on variability of the properties of yield (SLAFER *et al.*, 2014). Maize grain yield is a product of the interactions, compensation and phase actions of yield components at different stages of maize development (DOFING and KNIGHT, 1992). Grain yield may be equal regardless the different contributions of the certain yield components (MĄDRY *et al*., 2010) and mostly depends on the number of kernels per ear, number of kernels per row and number of kernel rows at higher densities (MILANDER *et al*., 2016). Maize grain yield and number of plants are not consistent and linear (HASHEMI *et al*., 2005; MANSFIELD and MUMM, 2013; NOVACEK *et al*., 2013, 2014), especially in regard to lower densities (BALKCOM *et al*., 2011; THOMISON *et al*., 2011; ROBLES *et al*., 2012; REEVES and COX, 2013).

The objective of the study was to determine the direction of variation of traits with respect to agro-ecological conditions for yield, dry matter production and morphological traits of the maize.

MATERIALS AND METHODS

Plant material and laboratory testing

Six maize inbred lines L1-L6 (FAO 400) and 15 hybrids (H12-16, H23-24, H43, H52-54 and H62-65), obtained by crossing of inbred lines according to the dialell scheme n(n-1)/2, were used in this study. A comparative field experiment with inbreds and hybrids was set up according to the randomised complete block design in four replications, in the location of Zemun Polje (44°52′N 20°19′E) in 2014-2015. Each genotype was sown in two five-meter long rows with the inter-row distance of 70 cm and the within-row plant distance of 20 cm. Samples of ten randomly selected plants were used for the analyses.

The following traits were observed: grain yield (GY) (t/ha), yield components: ear length (EL) (cm), number of kernel rows (NKR); morphological traits: plant height (PH) (cm), ear height (EH) (cm)); chemical traits: the whole plant dry matter (PDM) (t/ha) and the ear dry matter (EDM) (t/ha).

PH and EH, were measured during the growing season. Whole plants and ears in the milk stage were ground and used as samples for the determination of PDM and EDM. The samples were dried at the temperature of 60°C for 48 h, and after that were ground and then oven dried at the temperature 105°C.

After harvest, samples of five ears were drawn to determine EL and NKR.

Data of the Zemun Polje weather station were used to determine the average temperatures and precipitation sums during the growing season. Mean monthly temperatures in both years of investigation deviated from the reference period (1961-1990), pointing out to the tendency of mean monthly temperature to rise. The precipitation sum in 2014 and 2015 significantly deviated from the long-term average (1961-1990), and this trend was particularly obvious during the whole season of 2014.

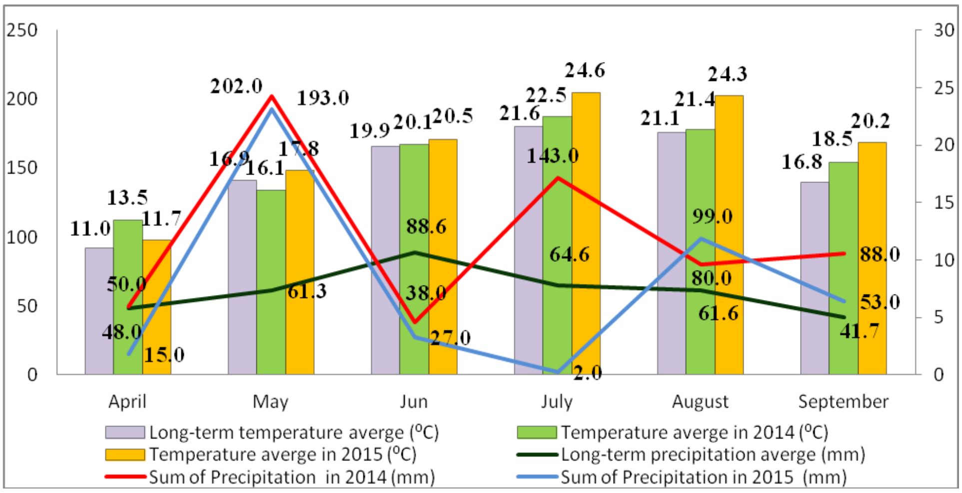

Figure 1. Average temperatures and precipitation in 2014 and 2015 and their variation from the long-term average

Statistical analysis of data

Obtained experimental data were processed by the adequate mathematical-statistical methods with the application of the statistical package IBM SPSS 19.0 (free of charge version) and the path analysis was carried out by the software IBM SPSS AMOS 19.0 (free of charge version).

Each of obtained parameters was processed by the analysis of descriptive statistics. The differences among observed maize hybrids were analysed by the method of analysis of variance (ANOVA) for the factorial trial set up according to the randomised design. The magnitude of the effect of each factor, as well as, their interactions, was established by the partial eta-squared coefficient. A relative dependence of traits was determined by the Pearson's coefficient, regression coefficient and the multiple regression relationship carried out by the path analysis (ARBUCKLE, 2010; ASTEREKI *et all,* 2017).

Linear regression:

$$Y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad i=1,2....n$$

Multiple linear regressions:

$$Y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i \qquad i=1,2....n$$

Nonlinear quadratic regression:

$$Y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \varepsilon_i \qquad i=1,2....n$$

where y = is a vector containing observed scores on the dependent variable, β_0 = is a vector representing the y-intercep, x_i is a matrix of continuously distributed or categorical independent variables, $\beta_{1..n}$ =is the vector of regression weights, and ε= represents the vector of residual or error or leftover scoring unexplained by the model.

RESULTS AND DISCUSSION

Variability of hybrid traits

Descriptive statistics was used to determine and estimate mean values of observed traits. The highest values were recorded for the yield in the hybrid H13, and the following yield components: NKR and EL in hybrids H64 and H13, respectively. Chemical traits EDM and PDM were the highest in the hybrid H14, whereas morphological traits EH and PH had the highest values in hybrids H23 and H13, respectively (Table 1). This is in accordance with the comparative examination on the inbreds. Inbreds L1 and L4 had the highest values for chemical properties. High values of morphological traits were recorded in inbreds L3 and L6, whereas the values of yield and yield components recorded in inbreds L3 and L4 were the highest. In the past 20 years, maize yields have been increasing, and one of the reasons for this is the increasing impact of the frequency of hot weather (HAWKINS *et al*., 2013). The yield recorded in 2014 and 2015 are not significantly different.

Grain is a main product of maize in terms of both, the yield and the nutritive value, and it raises the question of whether the most yielding hybrids are also the most suitable for silage production. According to PEJIĆ (1988), the basic criteria to be applied in the evaluation of maize hybrids as silage plants are: yield and the yield structure, digestibility of certain morphological parts of plants, effects of a genotype on organic matter digestibility and a hybrid response to ecological growing conditions.

Based on obtained results, morphological traits, PH and EH, had the greatest sample dispersion in 2014, and were followed by the chemical traits PDM and EDM, while the most stable traits were the yield components, NKR and EL, and yield in both years. Standard deviation (SD) was not greater than 4% of the estimated mean values (Table 2).

The intensity of variations of presented traits under impacts of weather conditions and genotypes is $R^2 > 0.900$ (Table 2), which is understandable considering the differences between 2014 and 2015, especially with regard to the precipitation sum (Figure 1). Environmental effects in both years of investigation, were very important for all traits except the EH. The significance of the genotype and its interaction with the agro-ecological conditions was confirmed by the ANOVA test (Table 2). Low precipitation sums in June, July and August, accompanied by dry spells during the growing season, especially during sowing, resulted in the reduced yields and differences in yields among hybrids (BIBERDŽIĆ *et al.*, 2018).

Table 1. Mean values of traits of hybrids and their parental components

Genotype	EDM		PDM		EH		PH		NKR		EL		GY	
	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd
L1	4,02	1,02	12,37	1,29	67,25	10,85	196,75	18,77	12,89	0,80	13,16	0,59	5,13	0,98
L2	4,09	0,33	11,16	1,09	66,58	5,17	182,38	4,98	14,66	0,64	14,47	0,67	4,97	1,96
3	4,53	0,44	10,76	0,96	70,13	12,05	194,88	12,08	11,93	0,53	15,60	0,54	6,14	0,70
L4	5,53	1,24	12,27	1,70	65,78	5,12	193,63	11,59	18,15	0,46	12,94	0,37	6,29	0,68
L5	4,32	0,92	10,70	2,17	67,85	14,82	187,75	20,07	11,80	0,35	16,32	0,51	5,65	0,47
L6	2,96	0,70	9,65	2,55	61,80	13,48	201,38	20,80	14,09	0,29	13,39	1,23	3,13	0,81
H-12	9,26	1,48	19,04	2,14	99,11	7,59	248,50	17,39	14,94	0,70	20,83	0,99	11,92	1,44
H-13	10,04	1,49	21,00	1,82	88,86	6,91	258,38	19,58	13,63	0,50	21,74	0,93	14,28	1,14
H-14	12,37	2,37	21,54	3,53	98,60	5,33	256,38	16,10	15,59	0,69	20,08	0,66	13,62	0,65
H-15	9,78	0,86	20,63	2,08	98,09	8,81	251,00	20,17	13,59	0,34	20,74	1,33	13,93	1,68
H-16	9,87	1,49	20,58	2,47	86,71	7,15	257,38	20,06	14,06	0,64	21,14	0,89	12,35	0,74
H-23	9,77	2,61	18,65	2,83	100,18	11,07	245,38	21,66	14,63	0,39	20,06	0,96	11,99	0,94
H-24	3,50	1,37	9,59	1,41	81,49	2,50	204,63	12,27	17,06	0,57	12,55	0,71	5,41	1,28
H-43	10,84	2,17	21,52	1,41	97,23	8,35	252,00	19,21	15,53	0,45	20,18	0,78	13,47	1,38
H-52	6,84	0,68	14,72	2,16	81,50	1,44	223,38	14,13	15,04	0,99	16,95	0,79	7,87	1,12
H-53	4,81	2,32	11,86	3,89	83,72	12,05	232,88	24,57	12,46	0,36	19,03	1,53	8,37	1,94
H-54	6,66	1,06	14,91	1,70	80,17	3,20	228,63	15,21	15,55	0,78	17,34	0,33	8,08	0,96
H-62	9,56	0,88	19,22	2,57	90,09	4,23	251,88	16,03	15,99	0,50	20,01	1,48	11,25	2,11
H-63	9,51	1,71	19,00	1,98	96,95	13,77	252,50	20,97	13,84	0,45	20,12	0,75	13,18	3,36
H-64	10,07	1,92	21,03	1,90	83,36	3,02	257,25	16,98	17,35	0,58	18,06	0,86	12,78	1,50
H-65	8,43	1,39	18,49	1,81	93,58	16,27	247,63	17,20	14,21	0,70	19,39	0,40	10,21	1,75
Average														
2014	8,15	3,47	17,02	4,72	90,48	13,61	244,91	29,83	14,82	1,70	17,08	3,13	9,21	3,75
2015	6,77	2,66	15,23	4,83	77,03	13,92	214,75	25,29	14,41	1,75	17,72	3,07	9,83	3,84
R^2	0,925		0,891		0,982		0,975		0,946		0,954		0,906	

Grain yield (t/ha) (GY), ear length (cm) (EL), number of kernel rows (NKR), plant height (cm) (PH), ear height (cm) (EH), yield of the whole plant dry matter (t/ha) (PDM) and the yield of ear dry matter (t/ha) (EDM)

Table 2. ANOVA, effects of factors on the expression of hybrid traits

Source	EDM	PDM	PH	EH	NKR	EL	GY
			p value				
Genotype	**	**	**	**	**	**	**
Year	**	**	**	—	**	**	**
G × Y	**	**	**	**	**	**	**

*p<0,05,** p<0,01

Grain yield (t/ha) (GY), ear length (cm) (EL), number of kernel rows (NKR), plant height (cm) (PH), ear height (cm) (EH), yield of the whole plant dry matter (t/ha) (PDM) and the yield of ear dry matter (t/ha) (EDM)

The relationship among traits

In 2014, morphological traits, EH, and PH correlated with the yield and one of the yield components, EL. The interrelation of all traits was high during the first year, but only the NKR was in correlation with the EH.

The coefficient of correlation was high among all traits in 2015. The NKR correlated with the EL at the significance level of $p<0.05$. Furthermore, EL and PH were correlated at the significance level of $p<0.05$. EL, EH and PH affected yield at $p<0.01$. Their correlation was also high (Table 3). Variability between examined traits in two years, especially correlations obtained between morphological and chemical traits of maize, occurred as a consequence of extreme weather conditions (ABENDROTH *et al*., 2011; MILANDER *et al*., 2016).

The impacts of weather conditions during 2014 and 2015 were the greatest on the morphological traits PH ($\eta=0.44$), EH ($\eta=0.48$) and the chemical trait, the accumulation of dry matter of both, PDM ($\eta=0.18$) and EDM ($\eta=0.22$) (Table4).

Table 3. Pearson's coefficient of correlation of hybrid traits during 2014 and 2015

Pearson's correlation coefficient	GY		NKR		EL		PH		EH	
	I	II	I	II	I	II	I	II	I	II
GY	-	-	0,06^{ns}	0,21*	0,82**	0,82**	0,84**	0,88**	0,69**	0,86**
KR			-	-	-0,10^{ns}	-0,16*	0,04^{ns}	0,24**	0,14*	0,29**
EL					-	-	0,86**	0,80**	0,74**	0,77**
PH							-	-	0,74**	0,87*
EH									-	-

I-2014 year, II-2015 year; grain yield (t/ha) (GY), ear length (cm) (EL), number of kernel rows (NKR), plant height (cm) (PH), ear height (cm) (EH), *p<0,05;**p<0,01, ns-not significant.

Table 4. Measures of Association

Sources of variation	EDM		PDM		PH		EH		NKR		EL		GY	
	η	η ^{2}	η	η ^{2}	H	η ^{2}	η	η ^{2}	η	η ^{2}	η	η ^{2}	η	η ^{2}
Year	0.22	0.04	0.18	0.03	0.44	0.19	0.48	0.23	0.12	0.01	0.03	0.00	0.08	0.00

Grain yield (t/ha) (GY), ear length (cm) (EL), number of kernel rows(NKR), plant height (cm) (PH), ear height (cm) (EH), yield of the whole plant dry matter (t/ha) (PDM) and the yield of ear dry matter (t/ha) (EDM)

η – Eta; η $^{2-}$ Eta Squared

Path analysis and regression coefficients

The intensity of the effects of morphological traits, PH and EH, on the yield component NKR was negatively orientated. A positive direction of the effects on the expression of traits was detected among morphological traits (PH, EH) and the yield component, EL, and among yield components (EL, NKR) and GY.

Impacts of remaining factors observed in this study (e1, e2, e3) were significant on the variance of yield components, NKR, EL and GY (Figure 2). The path analysis of the coefficients revealed that majority of traits, both morphological and yield components, affected the yield. Recent studies point out that the NKR and EL had the greatest direct effect on the yield (RAFIQ *et al*., 2010).

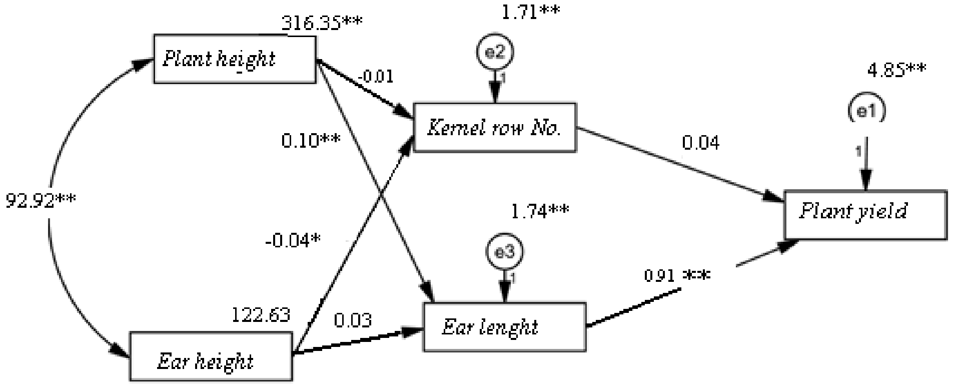

Figure 2. Path analysis of direct effects among investigated traits of maize genotypes

NKR, as a main yield component, had no greater effect on the yield formation during two years of investigation. The quadratic model was applied to estimate coefficients of regression and determination. The coefficients of determination were R^2-0.112 and R^2-0.207 in the first and the second year of investigation, respectively (Figure 3-a). The quadratic model of maize yield often occurs in locations with a great sum of precipitation (ASSEFA *et al.*, 2017), which was the case in 2014 when the sum of precipitation amounted to 601mm.

EL and GY are linearly dependent traits. EL with more than 60% affects the GY, which was confirmed in both years of investigation (Figure 3-b).

Fluctuations in weather conditions in the period from silking to maturation significantly affected GY of maize through the plant growth rate and the content of dry matter. The main factors in the production of dry matter of maize are changes in temperatures and solar radiation in the post-silking period (ZHOU *et al*., 2016).

Chemical components, dry matter of both, PDM and EDM, had a positive covariance with morphological traits, PH and EH. The yield component EL affected PDM, while NKR had no effects. The content of grain dry matter was related to NKR. The changes in variations as a consequence of changes in temperature and precipitation sums were significant for the content of PDM and EDM (chemical traits) and for PH and EH as morphological traits, (Figure 4).

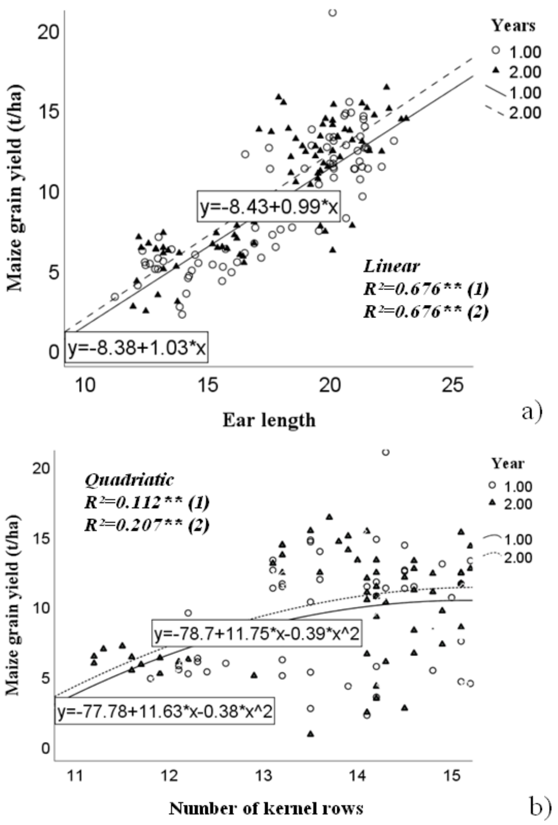

Figure 3. Effects of number of kernel rows (NKR) and ear length (EL) on grain yield of maize (GY)

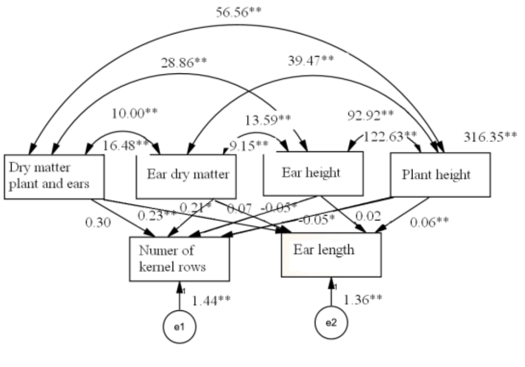

Figure 4. Path analysis of variance of direct effects on number of kernel rows (NKR) and the ear length (EL)

CONCLUSION

Within impacts of seasonal weather changes, agricultural production may be disturbed at all stages of development due to changes in temperature and insufficient water supply. Obtained results indicate that meteorological conditions affected the content of dry matter and plant growth of maize inbreeds and hybrids. The content of dry matter and morphological traits of maize increased in years with a higher amount of precipitation, such as 2014. The most yielding hybrids were not the most suitable for dry matter and bio mass production.

The ratio of the EL to EDM, as well as the ratio of the NKR to the PDM did not significantly depend on the environmental conditions. Meteorological conditions in 2014 and 2015 were the most favourable for H13 for yield, yield components and morphological traits. The chemical traits in 2014 and 2015 were the most pronounced in the genotype H14. In order to plan the production as precisely as possible and to achieve the projected yield, it is necessary to pay attention to the effects of temperatures and precipitation on variability of yield and yield components, by monitoring seasonal meteorological predictions and selecton of genotypes resistant to climate extremes.

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UTICAJ AGROEKOLOŠKIH FAKTORA NA MORFOLOŠKE OSOBINE KUKURUZA

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Izvod

U radu je analiziran prinos u odnosu na komponente prinosa i morfološke osobine u različitim agroekološkim uslovima. Cilj rada je bio da se oceni i odredi varijabilnost osobina (prinos, dužina klipa, visina biljke, visina klipa, broj redova zrna na klipu) i efekat sredine na intenzitet ispoljavanja pomenutih osobina. Kao matrijal korišćeno je 15 genotipova nastalih ukrštanjem 6 inbred linija, dve godine, na jednom lokalitetu. Dobijene srednje vrednosti ukazuju na bolje rezultate u ispoljavnju osobina kod hibrida u odnosu na roditeljkske komponente, sa manjom varijabilnošću. Broj redova zrna kao komponenta prinosa nije imala značaja na prinos, za razliku od dužine klipa, čiji je koeficijent determinacije $R^2$0.600, u obe godine proizvodnje. Uticaj spoljašnje sredine je veliki za sve osobine, osim za broj redova zrna. Na visinu prinosa značajno utiču varijabilne vrednosti visine biljke i klipa. Suva materija biljke i klipa tesno su povezane sa visinom biljke i klipa, ali isto tako zavise i od dužine klipa i broja redova zrna.

Variranja u odnosu na ekološke uslove proizvodnje su manje ili veće ali značajne za konačni cilj proizvodnje, prinos. Preovlađujući klimatski uslovi treba da su glavna smernica u projektovanju proizvodnje useva i izboru genetskog materijala.

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